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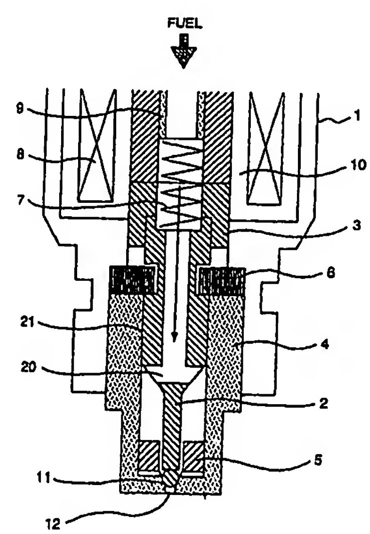
(54) Fuel injection valve

(57) A damper is formed between the nozzle and the plunger (2) of the fuel injection valve (1). This suppresses the bouncing of the plunger (2) and consequently suppresses secondary injections. Further, this can suppress depositions of chemicals on the fuel injection valve (1), generation of soot at improper combustion of fuel, and combustion control errors.

FIG. 1



EP 1 063 419 A2

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a fuel injection valve which supplies fuel to an internal combustion engine and more particularly to a fuel injection valve for fuel injection into a cylinder combustion chamber.

[0002] A method for preventing the plunger of the fuel injection valve from bouncing has been disclosed in Japanese Laid-Open Patent Publication No.9-273457 (1997). This method prevents the plunger of the fuel injection valve from bouncing by providing a dent on the surface of at least one of the plunger and a member opposite to it, holding fuel there, causing the fuel to be compressed just before the plunger hits the member, and thus preventing the fierce collision by the repulsive force of the fuel. The main object of the invention is to prevent bouncing of the plunger when the valve opens. However, if this method is applied when the valve is closed, the dent must be provided on the surface of the seat. Consequently, this method has a problem of letting the fuel go out through the closed valve.

SUMMARY OF THE INVENTION

[0003] The conventional fuel injection valves have not considered bouncing of plungers at the close of the injection valves and have been not effective to prevent generation of deposits on the tip of the fuel injection valve due to the secondary injection of fuel caused by bouncing and generation of soot due to fuel mists of greater particles.

[0004] The main object of the present invention is to solve the above problems.

[0005] It is an object of the present invention to provide a fuel injection valve which suppresses bouncing after the movable plunger touches the surface of the seat.

[0006] Another object of the present invention is to provide a fuel injection valve which suppresses secondary leakage of fuel through the fuel injection hole after the movable plunger touches the surface of the seat.

[0007] The above object is accomplished by limiting the opening of the valve by the housing of said movable plunger so that no fuel may come out through said fuel injection hole after said movable plunger presses against the surface of the valve seat.

[0008] Substantially, this object is accomplished by providing a small passage on part of the plunger between a fuel pool (from the surface of the valve seat and the guide of the plunger) and a fuel passage in the upstream side of said fuel pool.

[0009] Further, the object is accomplished by forming an oil-pressure damper with a fuel pool between said seat surface and the guide of said movable plunger, a fuel passage in the upstream side of said fuel pool, and said movable plunger.

[0010] Furthermore, the object is accomplished by controlling the resisting force made when said movable plunger hits said seat surface so that it may be a function of the moving speed of the movable plunger.

BRIEF DESCRIPTION OF DRAWINGS

[0011]

Fig. 1 is a sectional view of a fuel injection valve which is a first preferred embodiment of the present invention;
Fig. 2 is a graph showing a relationship between time and plunger lifts;
Fig. 3 is a sectional view of fuel injection valve having a damping means;
Fig. 4 is a graph showing a relationship between time and resisting force F by the damping means;
Fig. 5 is a graph showing a relationship between the damping function and the quantity of secondary injection.
Fig. 6 is a graph showing a relationship between plunger stroke and the quantity of secondary injection;
Fig. 7 is a graph showing a relationship between the set load of the spring and the quantity of secondary injection;
Fig. 8 shows forces acting on the plunger;
Fig. 9 explains the relationship of damping function, stroke, spring set load, and secondary injection;
Fig. 10 is a sectional view of a fuel injection valve which is a second preferred embodiment of the present invention:
Fig. 11 is a graph showing a relationship between fuel pressure and secondary injection;
Fig. 12 shows a repulsion force on the 90-degree valve seat;
Fig. 13 shows a repulsion force on the 60-degree valve seat;
Fig. 14 shows an influence of the L/D ratio of the injection hole;
Fig. 15 is a graph showing bouncing control by currents;
Fig. 16 shows the sectional view of the pressure wave block;
Fig. 17 shows the internal combustion engine using the fuel injection valve of the present invention;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Fig. 1 shows a sectional view of a fuel injection valve which is an embodiment of the present invention. The fuel injection valve 1 comprises a plunger 2 having a magnetic material 3, a valve seat 11, an injection hole 12, a nozzle 4, a swirler 5, a stopper 6, a spring 7, an adjuster 9, and a coil 8. The features of the structure of the fuel injection valve in accordance with the

present invention is that a clearance between the nozzle 4 and the guide 21 which determines the coaxiality of the plunger and the nozzle on the inner side of the plunger 2 is narrowed and only a passage 20 in the plunger is used to flow fuel downward in the guide.

[0013] The fuel comes from the top of the fuel injection valve, passes through the adjuster 9, the spring 7, and the internal passage 20 of the plunger 2 into the nozzle 4.

[0014] In the outer periphery of the plunger, the guide 21 which guides the plunger along the center of the nozzle blocks the fuel passage (isolating the upstream passage from the downstream passage). Therefore, the fuel must go downward into the nozzle through the passage 20 in the plunger. The fuel in the nozzle is given a swirling force by the swirler 5, passes through the clearance between the valve seat 11 and the plunger 2, then jets out through the injection hole.

[0015] Below will be explained how the fuel injection valve works. The plunger 2 is pushed against the surface of the valve seat 11 by the spring 7. The upstream end of the spring 7 is fixed to the adjuster 9 and the load of the load is determined by the fixing position of the adjuster 9. When an INJECT signal is given to the driving circuit, the electromagnetic coil 8 is turned on to form a magnetic circuit, which pulls up the magnet part 3 of the plunger 2. When the INJECT signal is complete, the electromagnetic circuit is turned off and the plunger 2 is pulled back strongly to hit the valve seat by the force of the spring 7. The plunger 2 is guided to the center of the nozzle by the guide 21 and the swirler 5. Further, the stroke of the plunger 2 is limited by the stopper 6. Contrarily, both the plunger 2 and the valve seat 11 of the conventional fuel injection valve are rigid and the plunger 2 bounces on the valve seat 11 by a repulsive force made when plunger 2 hits the valve seat at the close of the valve. Fig. 2 shows a relationship between time and amount of plunger lift. In the conventional fuel injection valve, such bouncing occurs repeatedly until the valve is completely closed. If the bouncing period is long or the plunger is lifted high by bouncing, secondary and tertiary injections will occur. As shown in figures, the fuel injection valve in accordance with the present invention prevents bouncing by making the plunger 2 soft-land on the valve seat. A damping means for that purpose is formed by a space surrounded by the plunger 2, the passage 20 in the plunger, the fuel injection hole 12, and the guide 21. Fig. 3 shows the principle of the damping means. Cylinder 33, piston 30, passage 31, passage 32, and fluid in Fig. 3 are respectively equivalent to the nozzle 4 of the fuel injection valve, plunger 2 of the fuel injection valve, the passage 20 in the plunger 2, the opening of the injection hole 12, and gasoline in that order. When the piston 30 goes down at a velocity V, the force F generating in the damping means is expressed by a formula in Fig. 3. The force F reduces in proportion to a square of the sectional passage area "a" (a sum of the sectional passage areas 31 (a_1) and 32 (a_2)) and increases in proportion to a square of the speed of fluid "v." In other words, when the fuel injection valve opens, the amount of lift of the plunger 2 reduces and simultaneously the sectional passage area "a" reduces. Consequently, the resisting force F of the plunger increases. As the plunger goes down, the speed of the plunger increases and the resisting force F increases. As the plunger 2 goes closer to the valve seat 11, the resisting force F of the plunger by the damping means, which reduces the speed of the plunger. This is assumed to increase the effect in suppressing bouncing. To increase this damping effect, it is preferable to narrow the sectional area of the passage in the plunger and to increase the sectional area of the plunger. The resisting force of the plunger is affected in proportion to the square of the sectional area of the passage in the plunger and to the cube of the sectional area of the plunger. The fuel injection valve of this embodiment increases the ratio "A/a" of the sectional area of the plunger "A" to the sectional area "a" of the passage in the plunger from 3.2 to 14.9. With this, the resisting force F of the plunger is increased about 27 times as strong as that of the conventional fuel injection valve. As illustrated in Fig. 5, the amount of secondary injection is decreased by reducing the sectional area of the passage in the damping means and increasing the resisting force of the damping means. However, if the sectional area of the passage is reduced too much, the resistance of the passage increases. This increases a time period between the input of an INJECT signal and the opening of the fuel injection valve and makes an insufficient flow rate of fuel.

[0016] To prevent bouncing, the damping means of the present embodiment comprises two configurations. The first configuration is pertaining to the stroke of the plunger. When the plunger stroke is made shorter, the speed at which the plunger collides against the valve seat becomes lower. Fig. 6 shows a relationship between strokes and amounts of secondary injection. When the plunger stroke goes shorter, the amount of secondary injection goes lower because of the above reason. However, when the plunger stroke is reduced, the flow rate of fuel goes low and the amount of fuel to be injected becomes insufficient. Therefore, the plunger stroke must not fall under a preset value.

[0017] The second configuration is pertaining to the set load of the spring. As illustrated in Fig. 7, when the set load of the spring goes higher, the force pressing the plunger also increases. This can reduce the bouncing stroke of the plunger and can suppress the secondary injection. However, when the set load of the spring is made too high, the force pressing the plunger exceeds the force pulling up the plunger at the opening of the fuel injection valve. This disables the fuel injection valve to open or makes the opening of the fuel injection valve improper. The set load of the spring can be determined by the mounting position of the adjuster 9 to which the spring is fixed. It is also possible to set an optimum

spring load by changing the spring constant.

[0018] As seen from above, the three configurations pertaining to the damping means, the low plunger stroke, and the high set load of the spring have an effect to suppress secondary injections. However, when the configurations are used individually and independently, it is difficult to prevent secondary injections without giving any influence to others. Fig. 8 shows how the resultant forces of these configurations work. When the fuel injection valve opens, the plunger receives a spring force, a valve closing force by a fuel pressure, and a force to damp the colliding force due to a shorter stroke. This resultant force collides the plunger against the valve seat. When the plunger starts to bounce, the repulsive force works to open the valve. At the same time, the resultant force of the forces due to the repulsive coefficients of the valve seat and the plunger, the spring force, the force due to the fuel pressure and the force made by the damping means works to close the valve. When the resultant vector of these forces is oriented to close the valve, a bouncing is suppressed. When the resultant vector of these forces is oriented to open the valve, a bouncing occurs. Therefore, the secondary injection can be suppressed by optimizing the damping means, the low plunger stroke, and the set load of the spring in combination.

[0019] Fig. 9 shows how the amount of secondary injection varies when every one of the three configurations is varied. As seen from the Fig. 9, a combination of these configurations can provide an area which nullifies the amount of the secondary injection without giving any influence to the others, preventing secondary injections.

[0020] Fig.10 shows a sectional view of the fuel injection valve which is a second embodiment of the present invention. The second embodiment is almost the same as the first embodiment but the structure of the damping means is changed. The passage of the damping means in the second embodiment is formed with the surface of the plunger guide and the inner wall of the nozzle 4. As shown in Fig. 10, the passage can be formed for example by cutting off four corners of a cylinder leaving the guide which is required. This structure can also has a damping effect and reduces the friction of the guide. Further, this structure is easy to be machined.

[0021] When this damping means is used in combination with the first embodiment, the same effect will be obtained.

[0022] Below will be explained another configuration which will has the same effect to prevent the secondary injection.

[0023] It is also possible to prevent secondary injections also by reducing the fuel injection pressure. This is because reduction in a fuel pressure reduces the absolute quantity of fuel to be injected as usually even when the plunger bounces. Further, when the fuel pressure on the plunger is reduced, the plunger is pushed back against the valve seat with less force and thus the speed of colliding the plunger against the seat also becomes lower. Further, as the flow rate of fuel is proportional to the square root of the pressure, the amount of secondary injection varies as shown in Fig. 11. However, the reduction in fuel pressure is limited because fuel pressure has a great influence on the particle size and passing-through ability of the fuel mist. For a fuel injection valve for injection into a cylindrical chamber, the injection pressure of 5MPa or higher is required. Therefore, it is very difficult to prevent secondary injections singly by reduction of fuel pressure.

[0024] Making the seating angle of the injection valve is also effective to prevent secondary injections. This method is effectively available to said embodiment. The principle is as follows: When the plunger hits the valve seat, a reaction force 50 generates as shown in Fig. 12. Vector 51 is the component of this reaction force along the axis of movement of the plunger, which will cause the plunger to bounce. When the seating angle is 90 degrees, a force of $1/\sqrt{2}$ times as strong as the collision force works to open the valve. When the seating angle is 60 degrees, a force of 1/2 times as strong as the collision force works to open the valve. As seen from this, the reaction force from the valve seat along the axis of the plunger can be reduced by making the seating angle smaller.

[0025] It is also possible to reduce secondary injections by increasing the L/D ratio (Length by Diameter) of the injection hole 12 as illustrated in Fig. 14. When the L/D ratio is great, fuel keeps lingering in the injection hole and will not go out of the hole even when the plunger bounces. The L/D value is also limited because the injection angle is limited and deposits by the lingering fuel may increase when the L/D value is increased.

[0026] As for an electromagnetic valve, the secondary injection can be reduced by currents applied to the coil at the end of injection. As illustrated in Fig. 15, the repulsion force can be suppressed by applying current 70 again to the coil just when the plunger starts to go back towards the valve seat by the spring force after the INJECT pulse is completed and the coil is turned off, giving a force to open the valve to the plunger, and thus reducing the collision speed of the plunger.

[0027] When the valve is closed abruptly, a striking wave occurs and lifts the plunger. To prevent this striking wave, a pressure wave block 60 is provided in the nozzle (see Fig. 16). This pressure wave block attenuates the striking wave caused by abrupt valve closing not to give any lifting force to the plunger. Namely, the pressure wave block suppresses the amount of bouncing by the striking wave.

[0028] Although all of the above embodiments explain using a ball valve, it can be substituted by a conical valve or a valve of the other shape. Further, said embodiments are also applicable to valves which are not driven electromagnetically.

[0029] The above embodiments used fuel injection

valves for injection into a cylindrical chamber which are used under conditions of an ordinary fuel pressure of 5 to 12 MPa, a frequency of 8 to 200 Hz, an injection period of 0.4 to 5.0 ms, and a combustion chamber pressure of negative pressure to 1MPa. The secondary injection tests were made under conditions of a fuel pressure of 7MPa and single-shot pulses of injection period 1.5 ms which are typical test conditions. The leakage of fuel after the fuel injection was video-recorded at a rate of 40500 frames per second in a close-up mode (in which the injection hole is magnified by 400 times). An incandescent lamp was used to illuminate the test system.

[0030] Fig. 17 shows the fuel injection valve of the present invention mounted on a cylindrical injection gasoline engine which directly sprays fuel into its combustion chamber. This kind of engine takes in air into the combustion chamber through the inlet port 71 at an optimum air flow rate which is controlled by the air flow controller 70 on the intake port 71. Fuel 76 is injected from the fuel injection valve 1 of the present invention, guided by the cavity 74 on the piston and gets to the ignition plug 72. The fuel combustion of this kind of engine is greatly affected by the status of the mixture of air and fuel droplets. If a secondary injection is made, a fuel-and-air mixture by the secondary injection is formed separately from the fuel-and-air mixture formed by the primary injection, which makes the propagation of a flame unstable and reduces the combustion controlling performance. Further, fuel droplets made by the secondary injection are not small enough to evaporate quickly and burns incompletely. This causes hydrocarbons and soot. Further fuel lingering on the tip of the fuel injection valve are quickly heated and evaporated, which causes deposition of chemicals. The fuel injection valve in accordance with the present invention can eliminate the above combustion troubles and increases the combustion control ability and the exhaust performance of the combustion engine.

[0031] The present invention suppresses secondary injection of fuel and consequently suppresses deposition of chemicals on the tip of the fuel injection valve, makes fine fuel droplets, reduces generation of soot and hydrocarbons, and makes combustion control easier.

Claims

1. A fuel injection valve comprising:

   a movable plunger (2) having a valve which opens and closes a fuel injection hole (12) by pressing against the seat surface containing the fuel injection hole (12) and departing from the seat surface and
   a driving device to move said movable plunger (2) reciprocally along the axis of said fuel injection valve (1);
   wherein the opening of said valve is limited by the housing of said movable plunger (2) having the valve so that no fuel may come out through said fuel injection hole (12) after said movable plunger (2) presses against the seat surface.

2. A fuel injection valve comprising:

   a movable plunger (2) having a valve which opens and closes a fuel injection hole (12) by pressing against the seat surface containing the fuel injection hole (12) and departing from the seat surface; and
   a driving device to move said movable plunger (2) reciprocally along the axis of said fuel injection valve (1);
   wherein an oil-pressure damper is formed with a fuel pool between said seat surface and the guide of said movable plunger (2) having a valve, a fuel passage in the upstream side of said fuel pool, and said movable plunger (2) having a valve.

3. A fuel injection valve comprising:

   a movable plunger (2) having a valve which opens and closes a fuel injection hole (12) by pressing against the seat surface containing the fuel injection hole (12) and departing from the seat surface; and
   a driving device to move said movable plunger (2) reciprocally along the axis of said fuel injection valve (1);
   wherein a small passage is provided on part of said movable plunger (2) having a valve between a fuel pool (from said seat surface to the guide of the plunger) and a fuel passage in the upstream side of the fuel pool and the total sectional are of the other passages is made smaller than the sectional area of said small passage.

4. A fuel injection valve comprising:

   a movable plunger (2) having a valve which opens and closes a fuel injection hole (12) by pressing against the seat surface containing the fuel injection hole (12) and departing from the seat surface; and
   a driving device to move said movable plunger (2) reciprocally along the axis of said fuel injection valve (1);
   wherein the resisting force made when said movable plunger (2) having a valve hits said seat surface is a function of the moving speed of the movable plunger (2).

FIG. 1

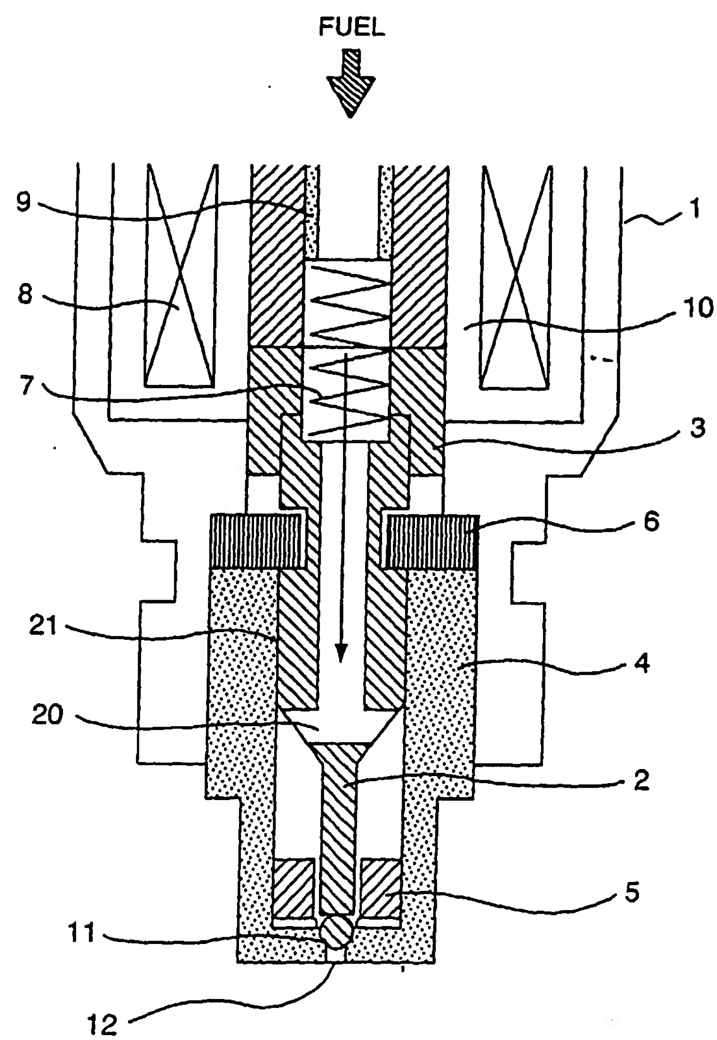


FIG. 2

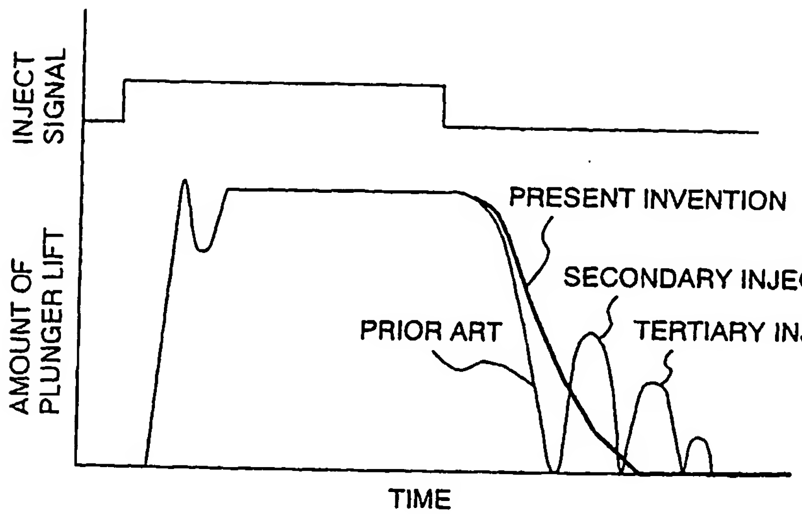
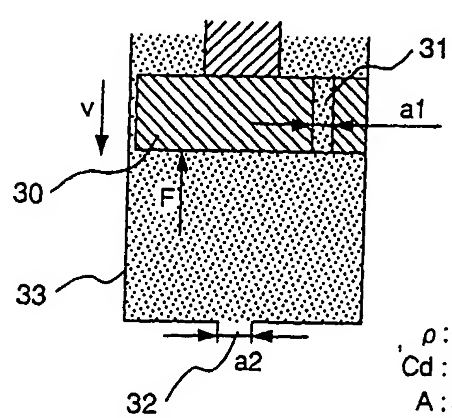


FIG. 3



ρ : DENSITY OF FUEL
Cd : FLOW COEFFICIENT
A : SECTIONAL AREA OF PLUNGER
F : RESISTING FORCE OF PLUNGER
a : SECTIONAL AREA OF PASSAGE

$$\boxed{F = A(\rho/2)(A^2/Cd^2\underline{a}^2)\underline{v}^2}$$

FIG. 4

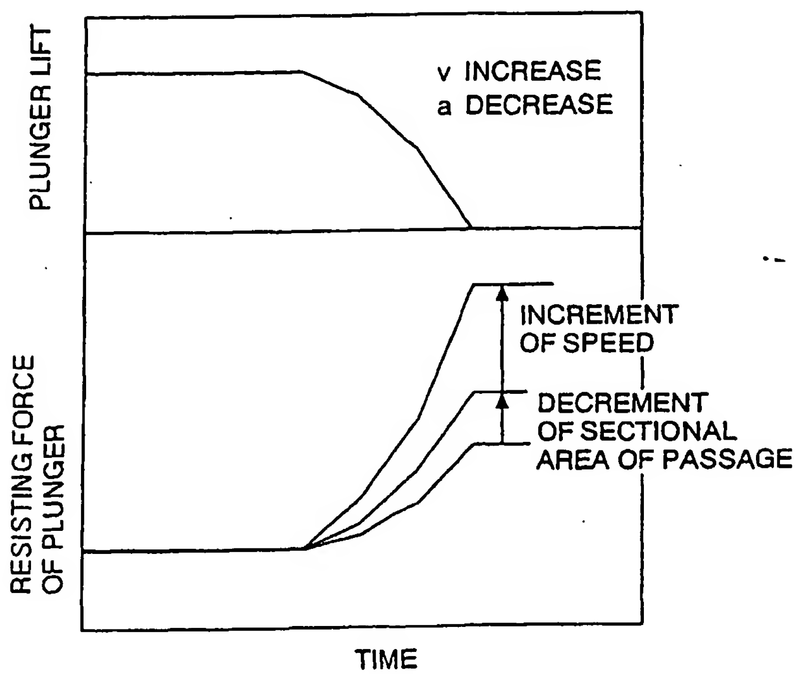

PLUNGER LIFT
v INCREASE
a DECREASE
RESISTING FORCE
OF PLUNGER
INCREMENT
OF SPEED
DECREMENT
OF SECTIONAL
AREA OF PASSAGE
TIME

FIG. 5

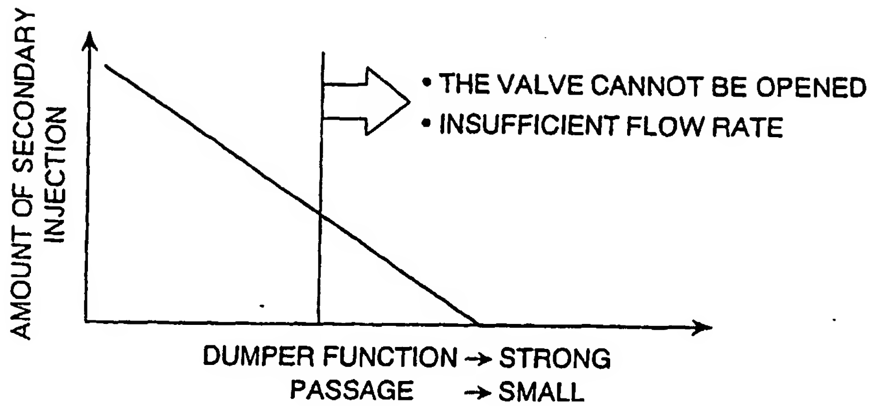

AMOUNT OF SECONDARY INJECTION
• THE VALVE CANNOT BE OPENED
• INSUFFICIENT FLOW RATE
DUMPER FUNCTION → STRONG
PASSAGE → SMALL

FIG. 6

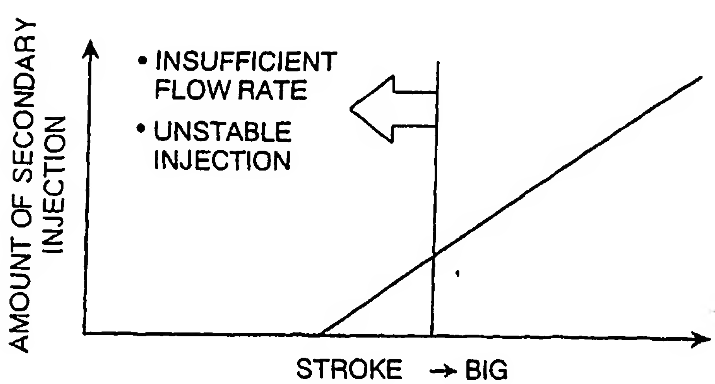

AMOUNT OF SECONDARY INJECTION
• INSUFFICIENT FLOW RATE
• UNSTABLE INJECTION
STROKE → BIG

FIG. 7

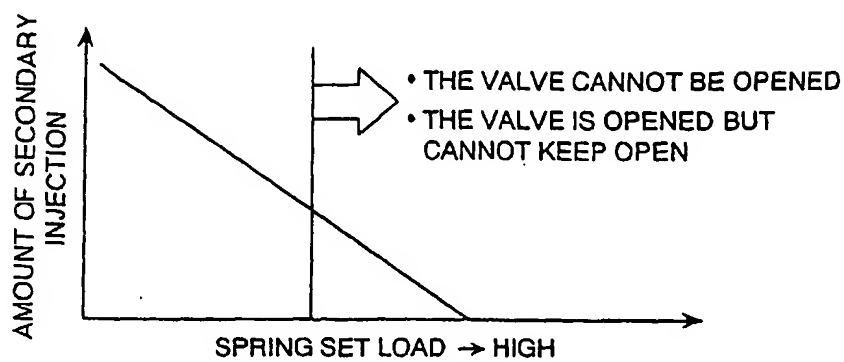

AMOUNT OF SECONDARY INJECTION
• THE VALVE CANNOT BE OPENED
• THE VALVE IS OPENED BUT CANNOT KEEP OPEN
SPRING SET LOAD → HIGH

FIG. 8

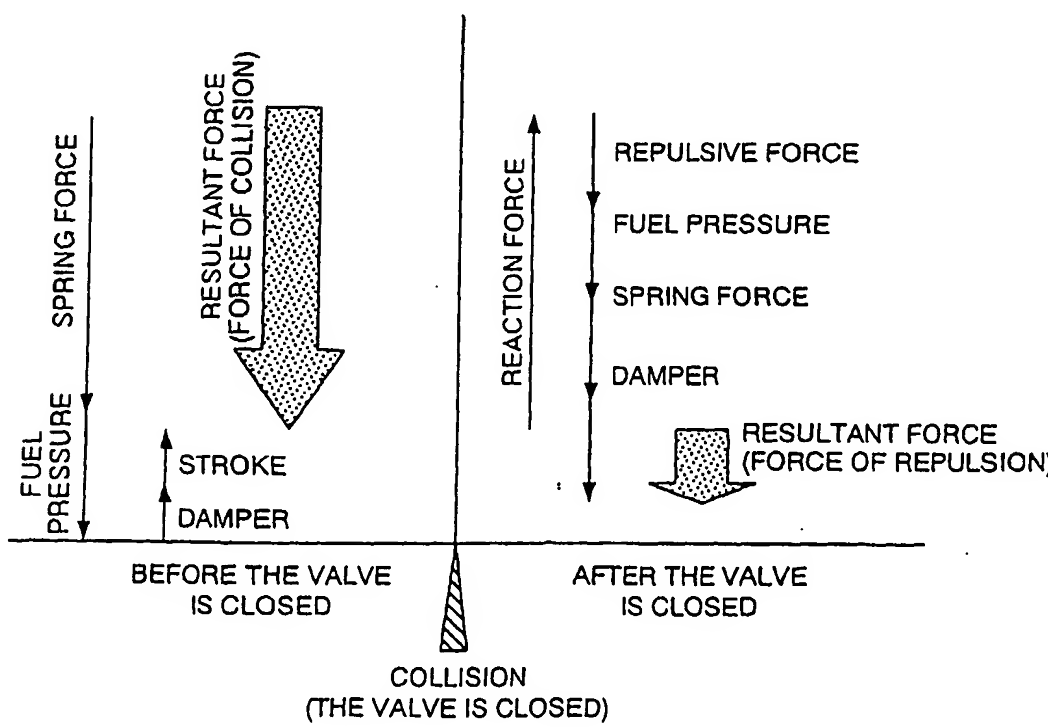

SPRING FORCE
FUEL PRESSURE
RESULTANT FORCE (FORCE OF COLLISION)
STROKE
DAMPER
REACTION FORCE
REPULSIVE FORCE
FUEL PRESSURE
SPRING FORCE
DAMPER
RESULTANT FORCE (FORCE OF REPULSION)
BEFORE THE VALVE IS CLOSED
AFTER THE VALVE IS CLOSED
COLLISION (THE VALVE IS CLOSED)

FIG. 9

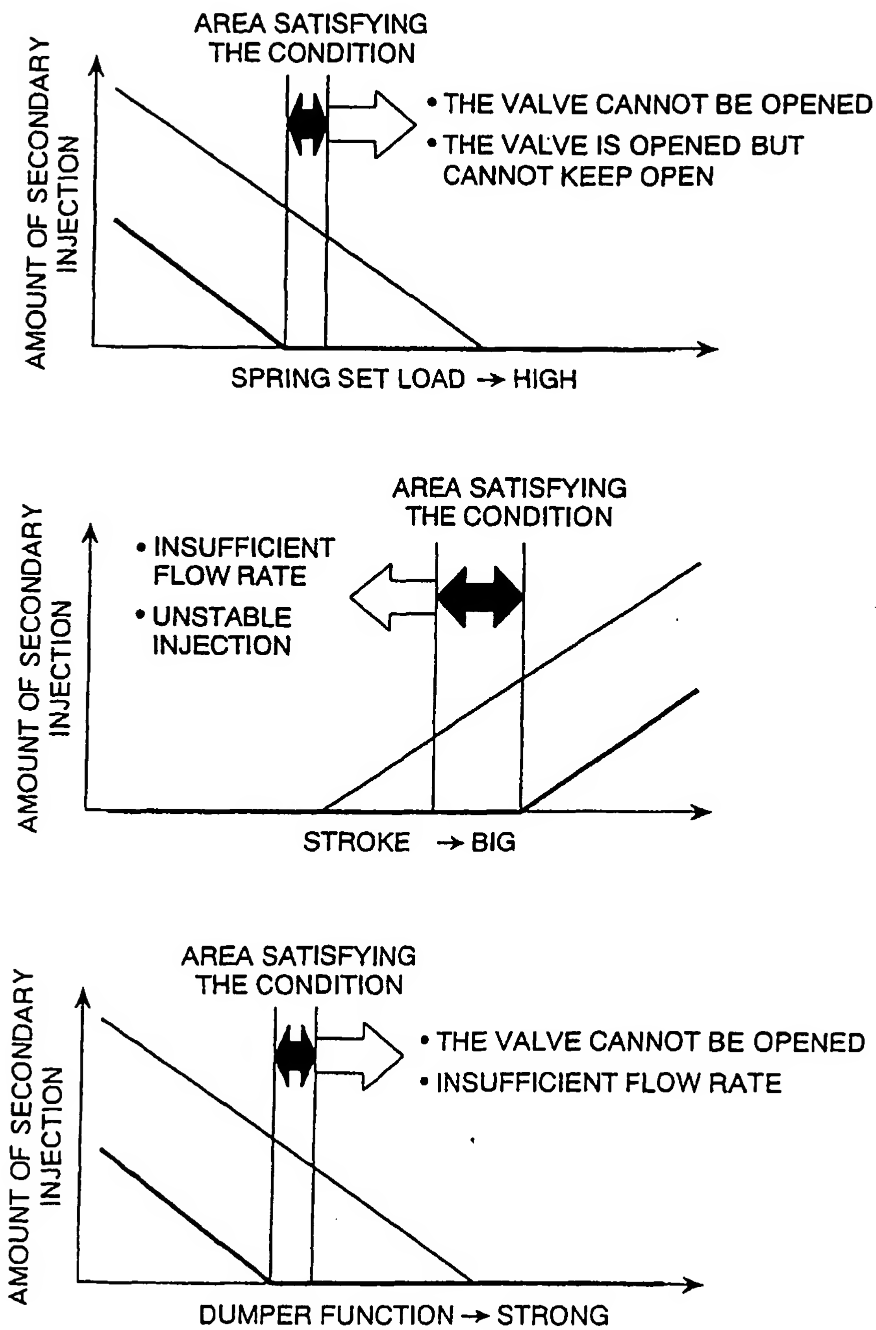

AREA SATISFYING
THE CONDITION
• THE VALVE CANNOT BE OPENED
• THE VALVE IS OPENED BUT
CANNOT KEEP OPEN
AMOUNT OF SECONDARY
INJECTION
SPRING SET LOAD → HIGH
AREA SATISFYING
THE CONDITION
• INSUFFICIENT
FLOW RATE
• UNSTABLE
INJECTION
AMOUNT OF SECONDARY
INJECTION
STROKE → BIG
AREA SATISFYING
THE CONDITION
• THE VALVE CANNOT BE OPENED
• INSUFFICIENT FLOW RATE
AMOUNT OF SECONDARY
INJECTION
DUMPER FUNCTION → STRONG

FIG. 10

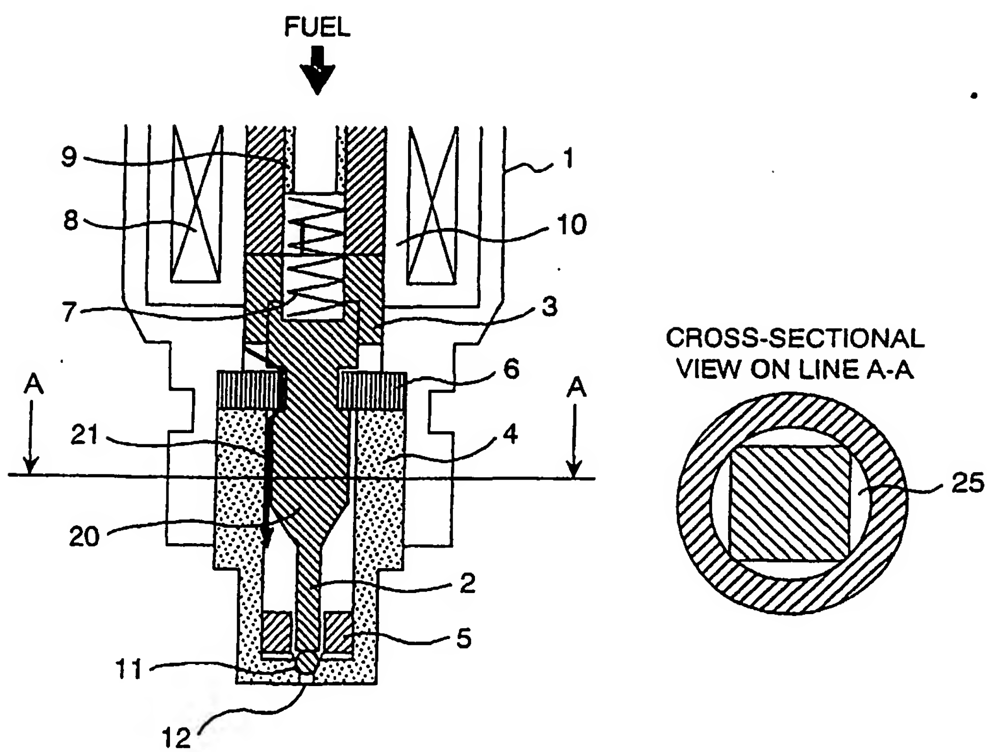
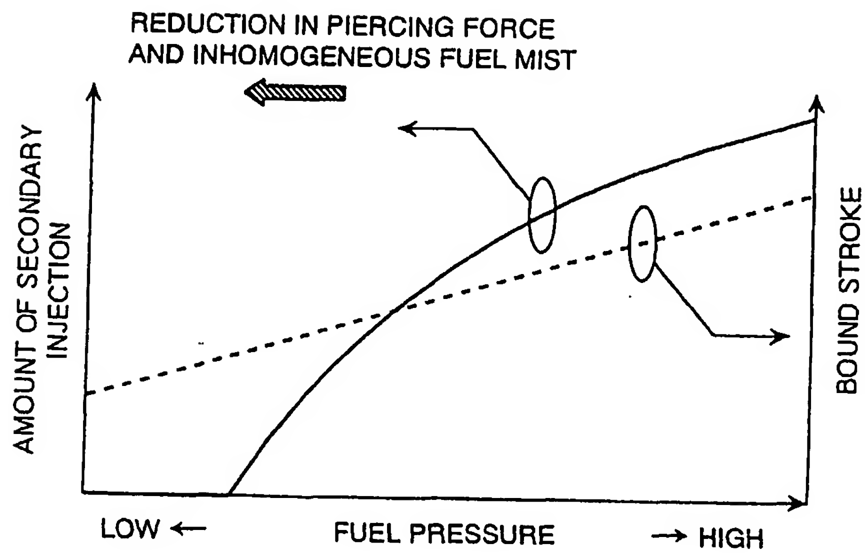

FUEL
9
8
7
A
21
20
11
12
1
10
3
6
A
4
2
5
CROSS-SECTIONAL
VIEW ON LINE A-A
25

FIG. 11



AMOUNT OF FUEL INJECTED Q	$\propto \sqrt{\text{FUEL PRESSURE}}$

FIG. 12

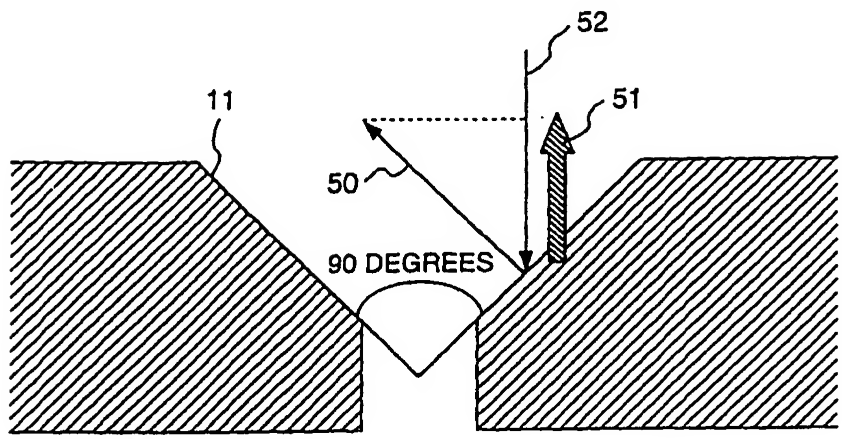


FIG. 13

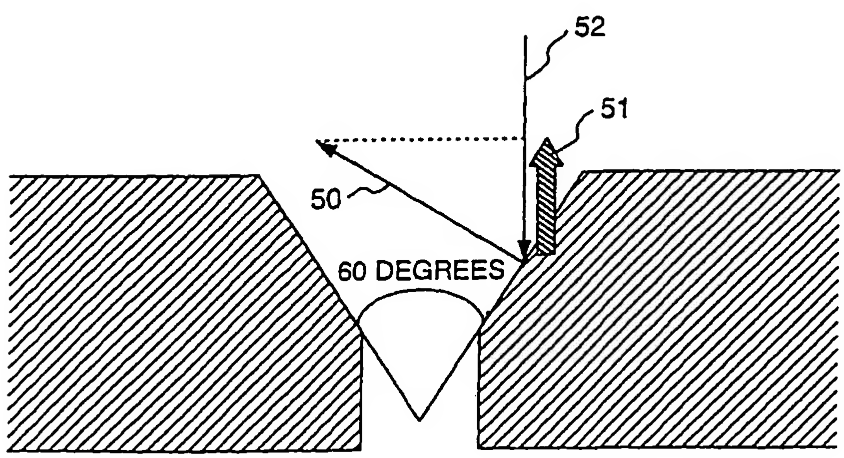


FIG. 14

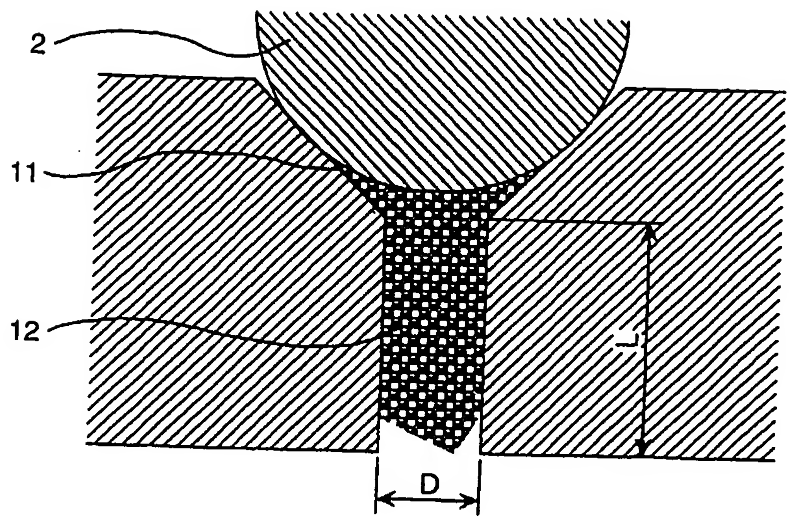


FIG. 15

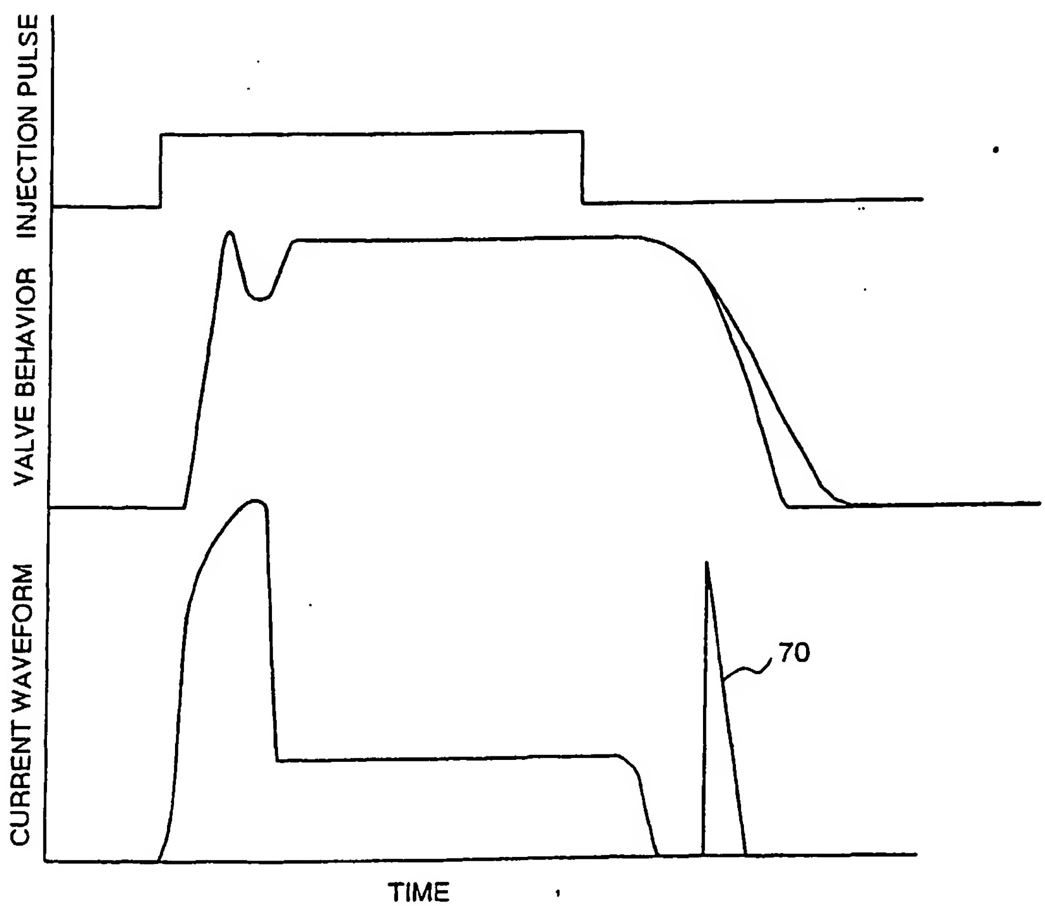


FIG. 16

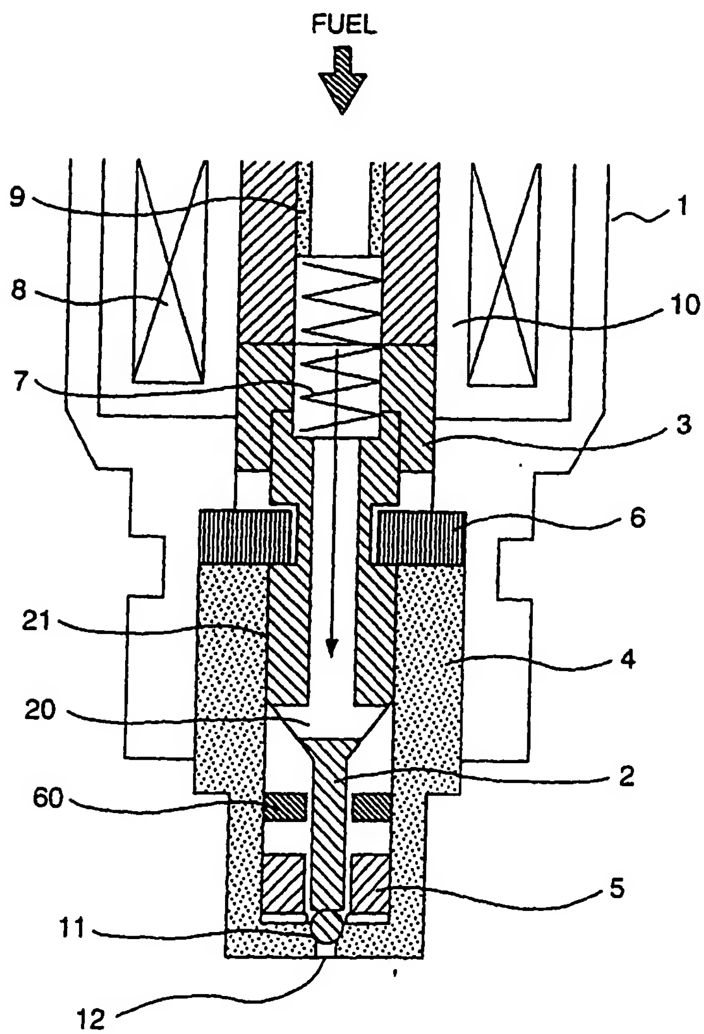


FIG. 17